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Effect of Urban Texture on Building Energy Performance

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ABSTRACT
Today, ongoing discussions on climate change, depletion of fossil fuels and energy efficiency emphasize the need for a more sustainable built environment and thus the need to reduce energy consumption in buildings and urban textures and reduce greenhouse gas emissions. Therefore the evaluation of building energy performance with a holistic approach, taking the effect of urban textures and microclimates into consideration has become very significant in the recent years. Urban texture is a commonly accepted expression including the form and height of buildings, the width of streets, their orientation, spatial configuration and arrangement in space intersection, vegetation and so on. This study aims to develop and suggest a model which allows the evaluation of the level of effects of the design parameters which should be considered at the scale of urban textures, on the energy performance of buildings to design sustainable, energy efficient built environments. In the first stage energy performance of a reference building modeled in different urban texture alternatives was evaluated. The evaluations are performed through DesignBuilder simulation program for the location of İstanbul representing temperate-humid climatic region. The parameters of aspect ratio (H/W) and orientation were used to develop different urban texture alternatives. In the second stage, analyses of outdoor thermal comfort of the existing condition and the condition with the added effect of vegetation for the alternatives with the lowest overall energy consumption were conducted with the ENVI-Met program. The thermal comfort parameters of air temperature, mean radiant temperature, wind speed and physiological equivalent temperature (PET) index were used to evaluate outdoor thermal comfort in streets. As a result, the urban texture alternative which achieved the optimum result for energy performance and with regard to outdoor thermal comfort was determined.

KEYWORDS
Sustainable Built Environment, Urban Texture, Building Energy Performance.

INTRODUCTION
With the rapid growth of urban areas all around the world, urban textures are considered to be the main source of CO_2 emissions responsible for climate change. Therefore, urban textures and buildings in these areas should be planned, developed and used optimally in relation to energy consumption and CO_2 emissions caused by the consumed energy. On the other hand, when the relation between urban textures and climate is examined, it is possible to conclude that design parameters including layouts, building forms, building envelopes, and landscape planning have an impact on the urban climate, and urban climate has an impact on the energy performance of buildings and on the use of urban open spaces. Therefore, the correlation between urban texture and building energy consumption underlines a complex balance that includes climate parameters and urban canyons and buildings. Thus, design of urban textures and study of building energy consumption within the designed urban textures to achieve sustainable built environment have gained speed. The term “urban texture” means a territorial, planning and constructive organization, which has homogeneous characteristics from the

point of view of the historical transformation and of the formal and dimensional relationship between public and private spaces (Tiziana and Marianna, 2013). Urban texture is a commonly accepted expression including the form and height of buildings, the width of streets, their orientation, spatial configuration and arrangement in space intersection, vegetation and so on (Ratti et al. 2005).To describe and model the interaction of the urban texture with the climate and energy, the following parameters should be considered: aspect ratio, street orientation, sky view factor, local and neighborhood scale, street trees and urban parks (Oke, 1976; Golany, 1995; Sanaieian et al. 2014, Jamei et al. 2016). The most important parameter among those that are considered to define urban textures that affect outdoor comfort conditions based on climatic characteristics is the ratio of average building height (H) to average street width (W). This aspect ratio, which defines the relations among buildings in the sections of urban textures, controls solar access and wind movements with limitations of orientation and causes changes in micro-climate data. Additionally, it can affect comfort conditions of the buildings within an urban texture. Urban textures in temperate climatic regions are mostly designed based on the building requirements to have access to solar radiation during a heating period, but the level of effect of this approach on outdoor conditions is not evaluated. Therefore, the H/W ratio is taken as the primary parameter in many studies aiming to analyze outdoor thermal comfort. The orientation effect is also taken into consideration to evaluate outdoor conditions according to changing aspect ratios (Toudert and Mayer, 2006; Andreou 2013; Kariminia et al. 2015; Yang and Li, 2015). Thus, parameters such as H/W ratio, orientation and the use of green spaces that strongly affect energy performances of buildings and outdoor thermal comfort conditions should be taken into consideration during the design stage. This study aims to develop a model with which, in addition to urban texture-building interaction, outdoor thermal comfort, can also be analyzed to design sustainable, energy efficient environments. The effect of the design parameters of urban textures (building height/street width, street and façade direction, vegetation) is analyzed using the alternatives defined for this purpose. The analyses are conducted for Istanbul representing temperate-humid climate where the heating period is longer than the cooling period and the design alternatives suggested based on the findings can be applied to other regions with temperate-humid climate conditions.

METHODS

The objective of the study is to evaluate the effect of urban texture alternatives developed with the defined design parameters on the outdoor comfort conditions and energy consumption of the buildings within those urban textures. In order to evaluate the effect of urban texture alternatives on energy consumption of the buildings, a reference building is defined for each urban texture and energy consumption is calculated for this reference building. The reference buildings are given in Figure 1. Thus, the steps to be followed in this study are given below.

Defining design parameters for urban textures

In order to analyze the outdoor thermal comfort level as well as the urban texture-building interactions, first the design parameters for urban textures should be defined. For this purpose, various urban textures were created based on the H/W ratio commonly used to define urban textures, and the effects of such urban textures were analyzed. In order to develop different urban textures, the H/W ratio is taken as 1.00 for uniform canyon; 0.50 for shallow canyon and 2.00 for deep canyon (Ahmed et al. 2015). To determine street widths for the three different H/W values used in the study, a 5-story residential building representative of the residential buildings commonly used in Istanbul was evaluated. The created urban texture alternatives with different H/W ratios are oriented to north-south, east-west, northwestsoutheast, northeast-southwest in order to determine the effect of orientation on outdoor thermal conditions (Figure 1).

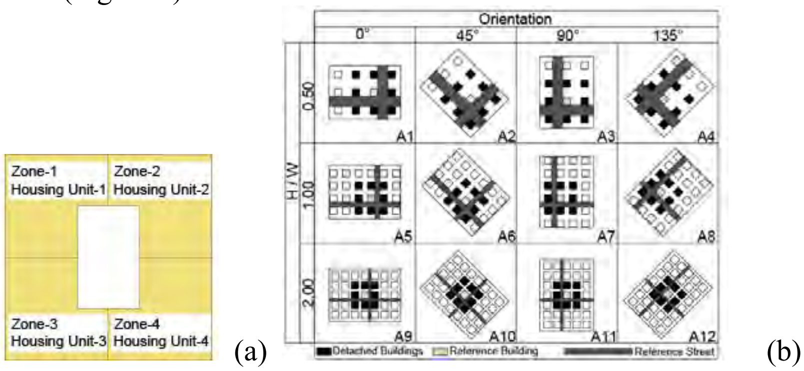

Figure 1. Floor plan of the reference building (a) and urban texture alternatives (b).

Defining design parameters for the reference buildings

In order to achieve general acceptance to define the design parameters for the reference building in the urban texture, residential building types built by TOKI (Housing Development Administration of Turkey), which plays an important role in the construction of residential buildings in Turkey, were researched and assessed. Based on the research, housing units with a building coverage of $100m^2$ were chosen. The A/V ratio (total external surface / building volume) is 0.2; the total floor area of building is 400 m^2 and the total building height is 15.00 m. While developing the details for the layering of building envelope of the reference building, the building envelope sections which are commonly used in the existing mass housing projects were used and the total heat transfer coefficient values (U, W/m^2K) of the opaque and transparent components of the building envelope comply with the limit values set for Istanbul in TS 825 (2013) (U_{wall}:0.57 W/m^2K, U_{g_floor}:0.53 W/m^2K, U_{roof}:0.38 W/m^2K, U_{window}:1.40 W/m^2K). The transparency ratio (total transparent area / total façade area) was assumed as 30% for all façades. There are four housing units on each floor of the building and each housing unit was accepted as a single conditioned zone (area which is heated/cooled). The indoor comfort temperature was accepted as 20 ºC for the heating period and 26 ºC for the cooling period.

Development of alternatives based on the defined designed parameters

In order to evaluate energy performance of the reference building, based on the urban textures with the H/W values determined to develop alternatives for design parameters, it is assumed that the urban textures consist of detached buildings in a study area of approximately 30,000 m^2. The number of buildings in the urban textures varies depending on the alternatives and is shown in Figure 1.

Evaluation of energy performance and outdoor thermal comfort of the alternatives

The DesignBuilder simulation program (DesignBuilder Software, 2018), which is the comprehensive interface of the EnergyPlus dynamic thermal simulation engine, was used to evaluate the energy performance of the reference building within the urban texture alternatives. Energy consumption data obtained in the calculations were reviewed and the ENVI-met program that can simulate the effects of vegetation in addition to complex urban textures based on daily micro-climatic dynamics was used to evaluate outdoor thermal comfort conditions at the street level for the developed urban texture alternatives. Annual heating, cooling and lighting energy consumption as well as overall energy consumption (heating + cooling + lighting) of the alternatives in which the reference building is in the urban texture or as a single building are shown in Figure 2.

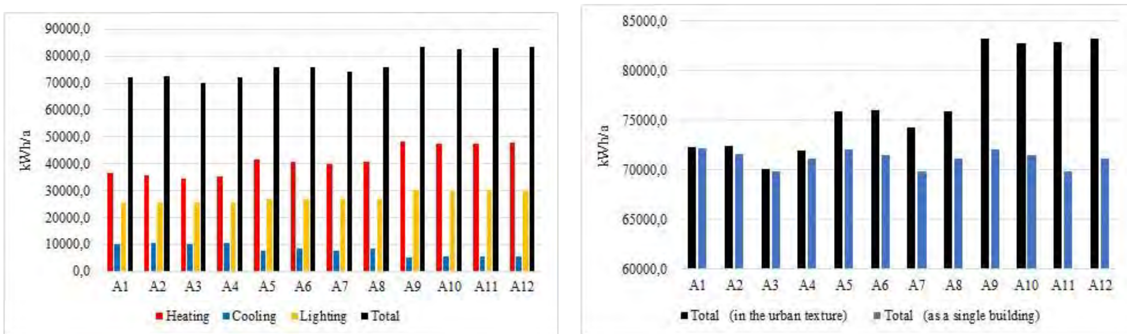

Figure 2. Energy consumption of 12 alternatives in which the reference building is located in the urban texture (a) and total energy consumption of the alternatives in which the reference building is located in the urban texture and the reference building is as a single building (b).

As seen in Figure 2, solar access of the housing units is increased with the proportional widening of street widths as the H/W ratio gets smaller, and consequently heating, lighting and total (heating + cooling + lighting) energy consumption decrease and cooling energy consumption increases. Additionally, as the heating energy consumption exceeds the cooling and lighting energy consumption, it is also determinant when the total energy consumption values are compared. When we compare total energy consumption of the alternatives in which the reference building is in the urban texture with the alternatives in which the reference building is accepted as a single building; the differences vary according to the aspect ratio. Since the streets are wider (30 m) in the four alternatives with H/W:0.50, very small differences in energy consumption are observed. However, due to the decreased street widths in 8 alternatives with H/W:1.00 and H/W:2.00 (15 m and 7.5 m respectively), the total energy consumption of the alternatives in which the reference building is modeled as single building is min. 5% and max. 16% less than the total energy consumption of the alternatives in which the reference building is in the urban texture. When the results for orientation are examined, due to the fact that the reference building in the alternatives has a symmetrical plan, it is possible to note that the percentage of change in energy consumption due to orientation is rather low. Among the 12 urban texture alternatives evaluated in this study, the highest heating and the lowest cooling energy consumption is achieved when the H/W ratio is 2.00. However, when the total energy consumption is taken into consideration, since the heating period is longer than the cooling period, heating energy consumption has more impact on the total energy consumption. Therefore, the alternatives with H/W ratio of 2.00 (A9, A10, A11 and A12) and the alternatives with the orientation angles of 0º, 45º and 135º (A1, A2, A4, A5, A6 and A8) do not give favourable results for total energy consumption. So, these alternatives are not included in the evaluation of outdoor thermal comfort in the next stage.

The outdoor thermal comfort evaluation is performed for the selected alternatives of A3 and A7 (with 90^{o} orientation and the aspect ratios of 0.50 and 1.00 respectively) which resulted in lowest total energy consumption in the first stage. The evaluation is done at street level, through ENVI-Met microclimate simulation model for a period of 24 hours on July 21st. The meteorological inputs are entered through simple forcing method through which temperature and humidity profiles in 24 hourly values are forced onto the simulation model. The standards TS 1576 (2012) and TS 12174 (2012) were used to define street layouts in the alternatives. The surface material for sidewalks is assigned as concrete. Besides the analysis of the base cases of A3 and A7, potential improvements by the use of vegetation were evaluated through the simulation of the urban texture alternatives A3-t (3 rows of trees) and A7-t (2 rows of trees) (Figure 3).

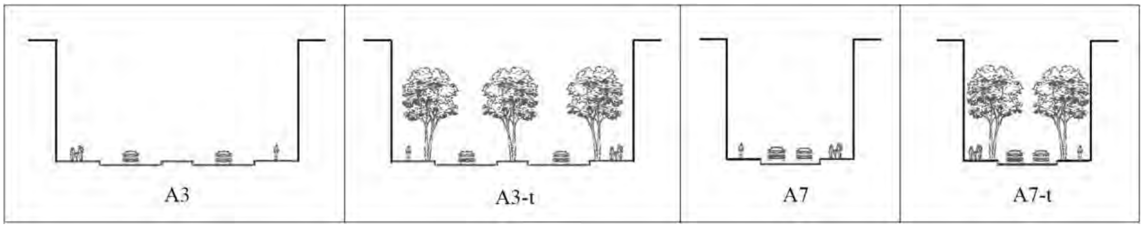

Figure 3. Street sections of alternatives for outdoor thermal comfort evaluation.

The thermal comfort parameters of air temperature (T_a), mean radiant temperature (MRT), wind speed (V_a) and physiological equivalent temperature (PET) (personal parameters based on "standard human" as defined in TS EN ISO7730 (2002) and with a summer clothing factor of 0.5 clo) were calculated at indicated street midpoints, at a height of 1.2m (z) from the ground (Figure 4).

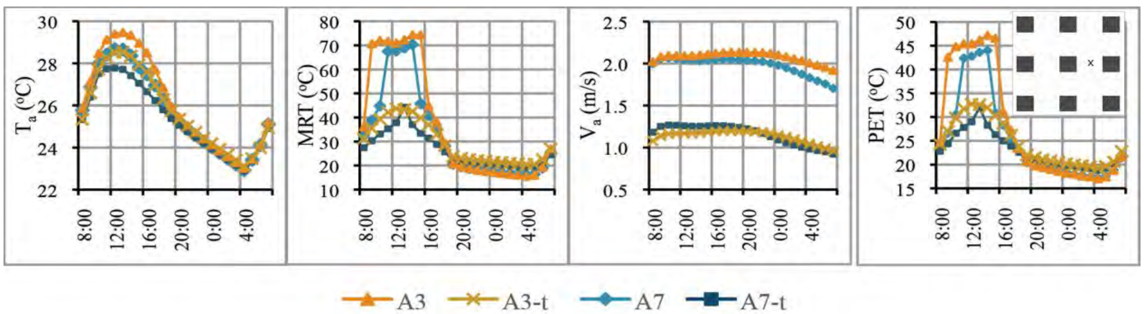

Figure 4. Temporal distribution of thermal comfort parameters.

When the hourly distribution of the thermal comfort parameters at the street midpoint are compared, the model A7 with H/W: 1.00 could have up to 16 ^{o}C higher PET values compared to A3 with H/W: 0.50 thus creating more comfortable outdoor urban spaces. The addition of trees has changed the mean radiant temperature and PET values in a similar manner. The addition of trees has reduced PET values at street midpoint up to 15 ^{o}C during day time and increased PET values slightly, up to 2 ^{o}C during the night time. During the day time, the mean radiant temperature in the streets with trees (A3-t and A7-t) is up to 32 ^{o}C lower, compared to the streets without trees (A3 and A7). On the other hand, after 19:00, the mean radiant temperature in the streets with trees gets slightly higher than the streets without trees. However, as the night time temperatures are already low, this result is not a significant drawback. Looking at the results for air temperature, the addition of trees has lowered the air temperature up to 1 ^{o}C around 13:00. Finally when the results for wind speed are compared, the addition of trees have reduced the air velocity up to 50%. Despite the reduction in air velocity and slight increase in PET values at night, the overall improvement in outdoor thermal comfort by the addition of trees is very significant.

CONCLUSIONS

Urban texture is the most important parameter that affects long term building energy consumption because an urban texture continues to exist for many years without any major change and affects the performance of the buildings that belong to that urban texture. Therefore, inclusion of the effects of urban microclimates in all evaluations of building energy performance, is critical for making correct decisions for sustainable, energy efficient buildings and urban texture design. This study aims to develop a model with which, in addition to urban texture-building interaction, outdoor thermal comfort, can also be analyzed to design sustainable, energy efficient environments. The effect of the design parameters of urban textures (building height/street width, street and façade direction, vegetation) was analyzed using the alternatives defined for this purpose for Istanbul representing a temperate-humid climatic region. The findings are compared and presented. However, similar studies using a high number of alternatives should be conducted in order to have an acceptable general conclusion.

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